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Visualizing Production Status in Time

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Abstract – **Real-time production status in graphical form provides critical information to manufacturing personnel to make timely decisions that can increase our production rate and reduce errors. The Pulse suite of tools provides schedule, production rates and forecasts, in-process inspection rates, and Takt Time in graphical form that can be quickly assimilated to produce a uniquely powerful view into the state of the production environment.**

I. Introduction

Production has always had access to production data in some form, however, this data is typically seen the next day, behind their actual occurrence, which doesn't work for managing the dynamic environment. Late, and hard to assimilate, data inhibits management from understanding the key production factors that can be altered to improve production. It also creates an environment that requires years of production experience in airplane manufacturing in order to develop the depth of knowledge necessary to manage production effectively.

Visualizing real-time production status in an airplane production system is critical for rapid decision making at all manufacturing levels. Our system provides schedule, production rates and forecasts, in-process inspection rates as well as Takt Time models in a form that can be quickly assimilated to produce a uniquely powerful view into the state of the production environment. This system provides unique insight into what changes to make to improve Manufacturing and Quality Inspection processes and may provide for significant opportunity to change our approach to balance in our production systems.

For example: A Shop Detail dashboard) provides unique visibility toward balancing the production line because it displays a production view and Takt Time balance view for comparison. The production view, i.e. Pulse view, contains the production schedule, the production rate, the inspection (in-process and completion) rates, and the Takt Time view display jobs per hour contrasted against a theoretical model for a balanced line. This gives management immediate visibility as to where the actual production levels should be at different levels, enabling management to quickly identify and make adjustments in resourcing and technical support to balance the production system.

This system provides unique features that support the production decision management process:

- A suite of visual controls that provide critical production factors that enable users to quickly and easily identify the health of the production system
- Program level drill-down allows clear and rapid identification and analysis of production and inspection bottlenecks
- Ability to compare production and inspection performance with a Takt Time balanced view
- Discrete time analysis of a day's performance via animation
- Andon alerts for increased speed of notifications to critical personnel via email

II. Background

The Lean production system is based on a foundation of the 5 "S" Lean Methodologies: Sort, Simplify, Sweep, Standardize, and Self Discipline. A base level of this methodology is needed in order to successfully implement a Lean production system. These are the basic tactics:

1. Value Stream – Provide an understanding of how value should flow through the business by documenting the current state, design and understand the future state, which allows the identity of gaps and improvement opportunities.
2. Balance the Line – Work is balanced hour by hour, allowing for all assemblers, installers, and support to continuously move product without delay.
3. Standard Work – Detailed instruction for how to perform work in the most efficient manner.
4. Visuals in Place – The ability to understand the health of production and take action based on what you see in seconds.
5. Point of Use – The ability to obtain what is needed to perform a task at the time the task is scheduled.
6. Feeder Lines – Remove work that is typically done "at the bench" from the main line, and provide the completed work at the time it is needed.
7. Breakthrough Redesign – Optimize processes that would reduce the critical path, cost, improved quality, etc.
8. Pulse Line – A pulse line is the final phase before implementation of a moving line and incorporates 5S and tactics 1 through 7. A pulse line moves to Takt Time, however, it is not continuously moving.
9. Moving Line – A moving line provides a visual means of managing the production system so that everyone

works to the same pace and feels the urgency to resolve problems.

Our implementation focuses on the relationship of real-time data utilizing tactics 2, 4, 5, and 8.

A. Tactic 2 - Balance

We refer to balance to mean the balance of the entire production system, not simply aligning work packages with equal numbers of employees on shifts. The scope of this must consider the work schedule, the assembler, and the support as the total solution for balanced work. In a perfect environment, an equal amount of work should be completed hour-by-hour across balanced shifts (1, 2, or 3). To model and achieve balance requires detailed production knowledge.

B. Tactic 4 - Visuals

We refer to visuals that provide information at-a-glance. This can be in the form of simple numbers or as complex as interactive real-time graphics, as long as the presentation of the information is providing the audience with a clear understanding of what the data relationships are with respect to the production environment. Our definition of an effective visual is that it conveys the health of any segment of the production environment at-a-glance.

C. Tactic 5 – Point of Use

We refer to this as information on-demand, which is, receiving the critical information at the time and the place where it is to be used. This can take various forms depending on the delivery device and the location. For example, a text only non-conformance alert may be sent to a Shop leaders Smart Phone so that they can be instantly aware of a problem. That same information can also be available on an internal web page as a graphic display.

D. Tactic 8 – Pulse Line

We refer to this in the context of a moving production line and measure the production efficiency utilizing the Takt Time model.

III. Takt Time

Takt Time is a Lean Manufacturing term that defines the desired production rate based on the available time per day divided by the required number of units to produce per day, referred to as daily demand.

$$\text{Takt Time} = \frac{\text{Available Time}}{\text{Daily Demand (units)}}$$

The value of understanding Takt Time is that it estimates the optimal balance for a production system. In our airplane production line, the balance is between our Manufacturing and Quality processes. Knowing this rate gives manufacturing a metric to stabilize production so that over or under production oscillation is minimized, thereby improving costs, reducing inventory buildup and improving quality consistency. Virtually any production process can be modeled using Takt Time if the constituent components are known and can be measured.

Takt Time is defined as the available production time divided by daily customer demand. More formally stated, Takt Time is defined by the formula: $T = Ta/Td$

Where,

T = Takt Time–Net available time divided by daily demand

Ta = Net available time applied work – the work time per period

Td = Time demand or customer demand– units required to produce per period

The fundamental success of modeling a process is identifying and defining the daily demand for that specific process. Disparate businesses define their daily demand as required for their specific business. For example, a sandwich shop might define their daily demand as the number of sandwiches per day or a steel company might use pounds of steel per day. The next step would be to define the production time by defining how many shifts, the length of each shift, and the time that should be subtracted that is not utilized in actually constructing the product, such as breaks and lunch, meetings and training.

A. Benefits of Takt Time

There are a number of benefits to using the Takt Time model for production lines; a critical benefit is bottleneck identification.

- Bottlenecks, work areas that operate inefficiently are readily identified.
- Identification and removal of non-essential tasks - Takt Time visibility provides strong evidence for removal non-essential tasks.
- Increases overall production throughput.

B. Collateral Effects of Takt Time

- As you organize your production line using the Takt Time model, some tasks may require decomposition to fit a standard work package time frame.
- Addition of failure recovery tasks into the Takt Time model may be necessary to accurately model a control code due to unexpected down times.
- Takt Time model visibility places stress on the production system, both mechanical and personnel, and may increase control code failures.

IV. Implementation

We developed a suite of web-based visualization tools that display production data for manufacturing at all levels. These displays consist of a Pulse view which provides schedule, production rates and forecasts, a Quality view that displays process inspection rates, a Manufacturing Rollup view that aggregates production rates and allows drill-down to lower levels, and a Takt Time view that displays the current Takt time. These views will be discussed in the following sections.

V. Takt Time Overview

Using an example Program level Takt Time model, the first two shifts are designed to be balanced and the third shift for line move and setup for the following day. The resulting Takt Time is 12 seconds. This means that if the production system is balanced, a task (job) should be completed every 12 seconds of the first two shifts. In general, as you drill-down in a production hierarchy, the Takt Time value will increase as you refine the production scope toward a single job; Takt Time will become the number of seconds available to complete that single job.

Figure 1.0 – First-Second Shift Table

The calculation for the FIRST-SECOND SHIFT table is as follows:

Takt Time

$$T = Ta/Td$$
$$T = (Ts \times S) / Td$$
$$T = ((Tn \times 60) \times S) / Td$$
$$T = ((Tm - (Tb+TL+Tx) \times 60) \times S) / Td$$
$$T = ((Sh \times 60) - ((Tb+TL+Tx) \times 60) \times S) / Td$$
$$T = ((8.5 \times 60) - (20+30+45)) \times 60) \times 2) / 4241 = 12$$

Where:

- Sh = Number of total hours in a shift
- Tm = Total minutes in a shift, Sh*60
- Tb = Total break time in minutes
- TL = Total lunch time in minutes
- Tx = Total time off the product
- Tn = Net time available to work in minutes, Tm-(Tb+TL+Tx)
- Ts = Net time available to work in seconds, Tn*60
- S = Number of balanced shifts
- Ta = Net time available multiplied by the number of balanced shifts, Ts*S
- Td = Daily Demand[a]
- T = Takt Time

[a]Daily Demand (Td), in this calculation, combines first and second shifts and is derived by subtracting the third shift demand from the Full Demand – the total demand of shifts one, two and three. Third shift is used primarily for resetting the line, etc. and is therefore not included.

A typical batch and queue production environment can cause significant waste in production flow. An example of how overall production time can be reduced by interleaving In-Process inspections with the work flow as compared to installers working several jobs to the point of an In-Process inspection and then placing all jobs up for inspection simultaneously.

The Pulse provides a visual representation of real-time data relative to both schedule and balance.

Schedule – display is available at the Program, Business Unit, and Shop level. This includes the schedule of jobs by hour, the actual jobs completed at that hour, plus the associated inspections that are occurring throughout the day. This is important in understanding the relationship between the inspection and build processes.

Balance – views are available at the same levels relative to Takt Time. All managers involved can quickly see the performance of the production system relative to balance. This is especially important in making decisions hour-by-hour in support of the build process, such as providing additional inspection support to a given area to mitigate an unexpected rise in demand.

Blue bars - represents the number of jobs completed at each hour. A completed job is defined as the work being physically performed plus inspected and signed-off as completed.

Orange and yellow lines - represent in-process and job-completed inspections respectively that are currently in-request or in-process of being completed. These “calls” disappear after the inspection is complete.

Black line - represents the non-conformance records.

Stop lights - measures performance to schedule, performance to team forecasts, and performance by hour. Red stoplights are indicators for leaders and support personnel to identify the source of the disruption and make resolution decisions rapidly. Management understands that if these indicators are not resolved quickly, that the consequences will affect production balance (Takt Time) and or Schedule (Delivery).

Panels - display various key information, such as: production schedule, rate and forecasts, the inspection (in-process and completion) rates and non-conformance tally.

In addition, the Pulse dashboard allows discrete time analysis with stop animation of a day’s performance, that is, it can playback the day’s activity. The playback allows users to identify evidence of processes waiting longer than expected or jobs that are not completed in the planned time frame. The result can be seen as spikes in inspections requests or as a “wave” in the inspection plots in the animation playback. It is also possible to manually move the animation slider bar control to analyze a specific time frame.

The Rollup is a concise summary view of the production system relative to balance. It provides multi-level mini-panels that display: Takt Time Plan and Actual, Takt Percentage, and a quick-status Stoplight signal. In addition, the Shop level panels have a Relative Performance bar. Using this bar, management can immediately identify which Shop(s) may need additional support. Clicking the Detail button on any panel brings up a detailed view.

The Shop Detail view allows a comparison between production and load balance Takt Time for the selected area.

This example depicts the schedule being missed during the first portion of the day and its negative effect on the balance. This is shown by the Takt Timeline (black line on the lower graph) being far above the calculated (expected) value (green line).

The opposite effect, where Takt Time is running below the calculated line would indicate that too many inspections are being requested at one time, i.e. the production is exceeding the expected rate. A Lean production system identifies this effect as a "batch and queue" system rather than a balanced production line. Should this occur, it should trigger an investigation at the Shop level as to why inspections are requested in such a manner, that is, if the inspectors waited for two hours to perform inspections, they would be idle during this time - an obvious problem. Receiving a batch of inspection jobs produces a surge in the inspection process and a vacuum in production resulting in an unbalanced production system.

This is a hypothetical example that demonstrates the insight that can be gained using the Shop Detail chart. In this example, there are two potential problems that are immediately recognizable.

Consider a surge of over one hundred jobs completed at 12:30am, far more than scheduled. This surge of completed jobs is also reflected in the Takt Time chart where the Takt Time line is shown below the calculated Takt Time. To determine what is causing the surge, one would display the previous day's Pulse. In this example, the Pulse shows a number of open inspections at the end of the previous day. This would account for the large quantities of jobs, apparently "being completed" the following morning. What is actually occurring is that the remaining jobs from the previous day's third shift are being inspected by Quality personnel during the morning shift of the following day, causing the apparent spike in production.

This hypothetical production surge situation should induce Quality Inspection to ask why this is occurring. One possible reason would be: production was batching jobs onto Quality Inspection at break, lunch or at end-of-shift.

The Pulse displays information based on an associated timestamp, because of this, it is easy to identify inspections that were initiated earlier in the day, but remain open. This identifies a common hypothetical situation in which a number of inspections are requested at 12:30am, but are still open at 7:30am, when this Pulse is being displayed. This situation should prompt Quality personnel to investigate because inspections should be completed within the normal inspection time. Quality Inspection needs to ask why so many inspections are initiated at 12:30am remain open at 7:30-8:00am. One possible reason is that production is "batching" jobs which will cause a surge in quality inspection that will resonate back into the production cycle causing it to oscillate.

The Pulse process provides Managers, Team Leaders and Support Personnel with a mechanism to quickly identify and take action to mitigate situations that may affect production. In the example process flow shown in Figure 7.0, it is possible to follow the Takt Time Rollup Screen from the beginning of the shift, and quickly see where adjustments can be made to mitigate conditions that are less than what we should expect from a balanced plan. The dual path also allows the process to flow directly to potential schedule questions that may drive adjustment in order to achieve both schedule and improved balance. The option to have direct electronic notification through both paths gives the user the ability to quickly respond to the areas in need. The Pulse process is superior to the traditional process which would only be able to see what happened at the end of the shift or perhaps the next morning depending on the user's schedule. Additionally, the traditional process would typically be done during a staff meeting vs. addressing the situation within minutes.

The power of our methodology is that it uses both the production view together with the Takt Time view to provide a better diagnosis of production problems. For example, if there is a spike in production shown on the Pulse view, the Takt Time view will reflect the degree of system imbalance. With a traditional schedule versus production view there is no measure of balance and so the amount of correction to the system will be based solely on the spike and experience of the management who will interpret its meaning, this will likely result in a less than optimal change. With our approach, management can know the degree of system imbalance and make greater or lesser changes based on the degree of imbalance shown in the Takt Time display.

Quality Inspection personnel can view performance on in-process inspection at a Shop level. This view provides: a statistical frequency distribution, average, standard deviation, minimum, maximum and range values for inspection completion time. It could indicate areas to study to determine what is causing the broad distribution in inspection time and how it can be mitigated in mitigated in the future.

When the average inspection time exceeds Customer expectation, it is an indication that the Shop production has a high probability of delay. An example would show a wide distribution of inspection times and many are too high on the average.

An electronic Andon subscription service has been added for Managers that allows them to be notified of specific conditions during the production day. We currently implement two Andons, one for performance and one for quality inspection.

- Band Notification –the Pulse system monitors shop performance and if a shop falls above the Band, an email notification is delivered to those who have subscribed to the Band notifications for that shop.
- Inspection Notification –the Pulse system monitors the Call Board and if a shop has a request for non-conformance of a part or assembly, an email notification is delivered to those who have subscribed to the inspection notifications for that shop.

Both are used today by Support Station and Manufacturing personnel as a quick indication that emergent action is required.

Our vision is to provide at-a-glance "health" metric views in critical areas of production to facilitate rapid decisions for production and inspection for the purpose of increasing our production rate and reducing errors. We developed and deployed the Pulse, Quality and Takt Time views described in this paper into the Boeing 777 Airplane production line during 2012.